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A Review of the Physical and Biological Characteristics of the Bahía Magdalena Lagoon Complex (Baja California Sur, Mexico)

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Abstract.—The Bahía Magdalena lagoon complex (BMLC) is an extremely productive and biologically diverse embayment on the Pacific coast of Baja California Sur, Mexico, and one of the most important fishing ports in the state. Local hydrologic conditions are largely determined by the differential influence of the California Current and California Countercurrent, with upwelling also affecting the physical characteristics of west–central Bahía Magdalena. Because of its subtropical location and variable hydrology, the BMLC is considered a transitional zone between temperate and tropical faunal regions. Tropical species are dominant among most taxa, especially in Bahía Almejas, but species composition is highly variable and coupled with environmental conditions.

The geographic orientation and physical characteristics of the Bahía Magdalena lagoon complex (BMLC), located on the Pacific coast of Baja California Sur (BCS), Mexico (Fig. 1), combine to create a contiguous system of shallow canals, intertidal sand flats, and embayments that is highly productive and biologically diverse (Alvarez–Borrego et al. 1975; Nienhuis and Guerrero–Caballero 1985; Cruz–Agüero et al. 1994). Because of its subtropical location, intermittently dominant current regimes (California Current and California Countercurrent), and seasonal upwelling (Bakun and Nelson 1977; Ibarra–Obando et al. 2001), the BMLC is situated at a transitional zone between temperate and tropical faunal regions (Briggs 1974; Brusca 1980). A great variety of marine flora (Sánchez–Rodríguez et al. 1989; Gárate–Lizárraga et al. 2001) and fauna (Castro–Aguirre and Torres–Orozco 1993; Félix–Pico and García–Domínguez 1993) therefore occupies this region as either eurythermal resident species or seasonal transients.

The shallow, protected waters of the BMLC are also typically warmer, more quiescent, and more productive than adjacent offshore waters (Acosta–Ruíz and Lara–Lara 1978; Obeso–Nieblas et al. 1999; Lluch–Belda et al. 2000), creating prime nursery conditions for a variety of vertebrate and invertebrate taxa, including: crabs (Sánchez–Ortiz and Gómez–Gutiérrez 1992), shrimps (Flores–Castanon 1980), bony fishes (Castro–Barrera 1975; Gutiérrez–Sánchez 1997), elasmobranchs (Guardado–France 1976; Villavicencio–Garayzar 1995; Bizzarro et al., 2007), and marine mammals (Rice et al. 1981; Ramírez–Espinosa 1990; Chaves–Rosales and Gardner 1999). Eelgrass (*Zostera marina*) and surfgrass (*Phyllospadix torreyi*) reach their southern limit at the BMLC (Riosmena–Rodríguez and Sánchez–Lizaso 1996; Santamaría–Gallegos et al. 2003). Mangroves also replace salt marshes as the dominant littoral vegetation in this region (Brusca 1980; Ibarra–Obando et al. 2001). Both seagrass beds (e.g., McRoy and Helfferich 1977; Connolly 1994) and mangrove prop roots (e.g., Robertson and Duke 1987; Morrissey and Gruber 1993) provide habitat and nursery functions for a great variety of species, thereby further enhancing nursery potential and biodiversity of the BMLC.

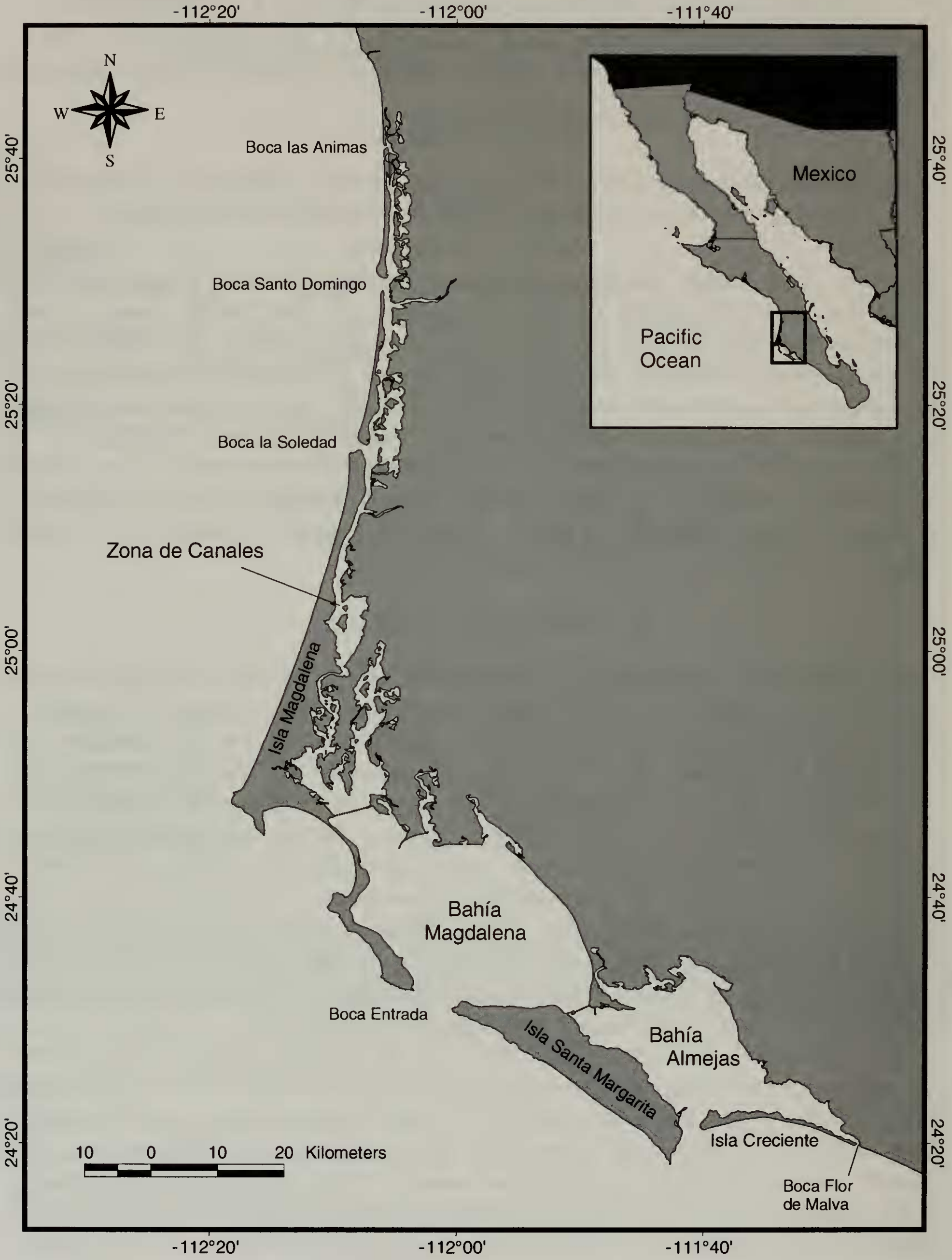

Fig. 1. The Bahía Magdalena lagoon complex, located on the Pacific coast of Baja California Sur, Mexico (see inset map). Dashed lines represent boundaries between regions.

Because of its considerable productivity, the BMLC contains abundant populations of several commercially harvested invertebrates and fishes and is considered one of the most important fishing ports in BCS (Cruz–Agüero et al. 1994; Obeso–Nieblas et al. 1999). Both industrial (Casas–Valdez 1987; Robinson et al. 2000) and artisanal (Gutiérrez–Uribe 1987; Rámirez–Rodríguez 1987; Salazar–Hermoso and Villvicencio–Garayzar 1999) fisheries occur in local waters. Large vessels (barcos) typically operate out of Puerto San Carlos, northern Bahía Magdalena or Puerto Adolfo López Mateos, Zona de Canales (Félix–Uraga et al. 1996), but a processing plant has also been active historically at Puerto Alcatraz in Bahía Almejas (Casas–Valdez 1987). Artisanal fishermen use small fiberglass vessels (pangas) and reside among the many coastal towns and fishing camps within the BMLC (pers. obs.).

Although the BMLC is of great biological and economic importance, limited historical information is available from this region and no comprehensive account of its physical and biological properties has been published. A Japanese researcher produced the first known scientific work from the BMLC, a 1913 technical report detailing fishery resources (especially abalones, *Haliotis fulgens*, *H. corrugata*, and spiny lobsters, *Panulirus interruptus*, *P. inflatus*) of Bahía Magdalena (Takasaki 1913). This report, however, was unknown to the western scientific community until Chapa–Saldaña published a translated version in 1962. Although both Japanese and Mexican fisheries operated in this area during the early and mid 1900s, additional relevant scientific publications were essentially limited to biological and taxonomic descriptions of local organisms (e.g., Dall 1918; Bartsch and Rehde 1939; Beebe and TeeVan 1941a, b). Knowledge expanded greatly in the mid–1970s, however, as several seminal studies concerning hydrology (Alvarez–Borrego et al. 1975; Acosta–Ruíz and Lara–Lara 1978), potential fisheries (Matthews and Druck–Gonzalez 1974 a, b; Mathews and Espinoza 1974; Mathews and Guardado–France 1974), and socio–economic development (Mathews 1975) were published.

Based on the interest generated by these publications and the increasing biological and economic importance of this region, the Mexican scientific community began to focus attention on the BMLC. The Centro Interdisiplinario de Ciencias Marinas (CICIMAR; La Paz, BCS) established a hydrological monitoring program in 1980 and has since become a primary source for scientific information about this region. Scientists and researchers from the Universidad Autónoma de Baja California Sur (UABCS; La Paz, BCS) also have published several studies in recent years and conduct ongoing research in the BMLC. To date, more than 100 scientific papers describing physical or biological characteristics and fisheries of this region have been published. Most of these works are printed in Spanish–language journals by Mexican authors, but English–language publications and American researchers have become more frequent. Many undergraduate and graduate theses projects also have been conducted in the BMLC, with the great majority completed by students from UABCS and CICIMAR, respectively.

The objective of this study is to describe the physical and biological characteristics of the BMLC, based principally on a comprehensive review of pertinent scientific literature. Supplemental information pertains mainly to Bahía Almejas and was provided through personal observations, Geographic Information Systems (GIS) spatial analysis methods, and analysis of sediment samples. This review is intended primarily for use by marine scientists, naturalists, and resource managers to provide a better understanding of the extent of historical work conducted in the region and to hopefully stimulate the development of future research projects.

Materials and Methods

The majority of the information used in this review was compiled from published scientific literature describing physical and biological characteristics of the BMLC. The following search engines were initially used to locate citations: Aquatic Sciences and Fisheries Abstracts, GeoRef, Biosis, Web of Science, and Zoological Record. After relevant manuscripts were obtained, their literature cited sections were perused for

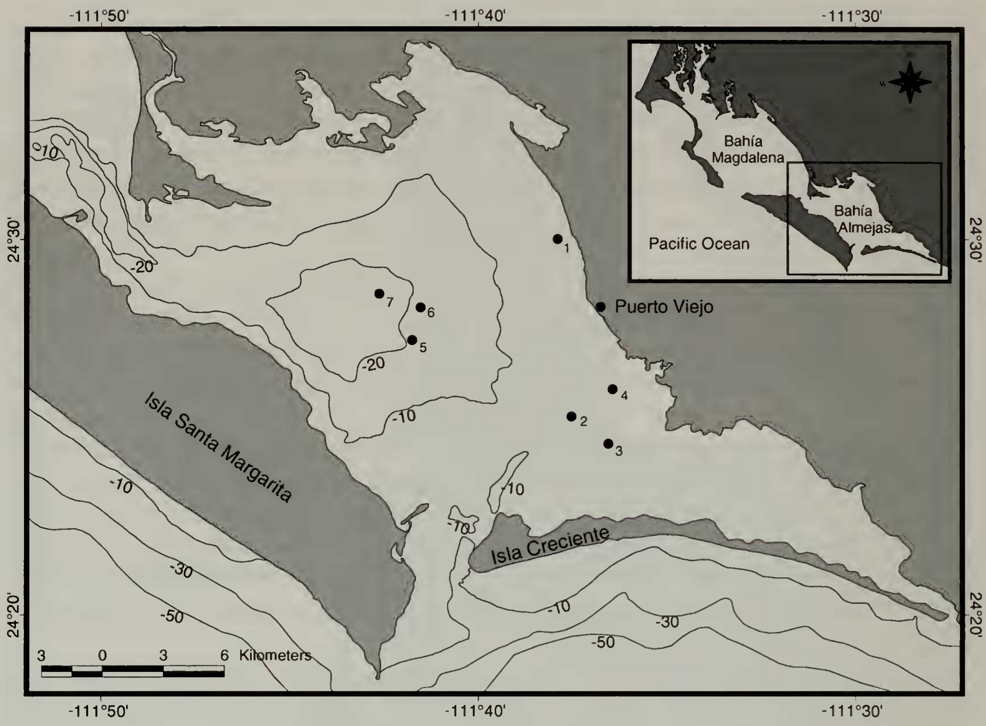

Fig. 2. Bathymetry profile of Bahía Almejas and surrounding regions, including location of sediment samples. Isobath values are listed in meters.

additional references. Mexican colleagues from CICIMAR, the Instituto Nacional de la Pesca, and the Centro de Investigación Cientifica y Educación Superior de Ensenada were also contacted to obtain supplemental literature that may have been overlooked during previous searches, especially unpublished Mexican theses. Pertinent literature was accumulated and examined, regardless of publication language. Abstracts from conference proceedings were used when peer–reviewed publications were unavailable. Personal observations made primarily in Bahía Almejas during summer months (June–August) from 1998–2002 were incorporated as deemed appropriate.

Geographic Information Systems technology, specifically ArcView® and ArcGIS® software, was used to determine surface area of the three BMLC regions (i.e., Zona de Canales, Bahía Magdalena, and Bahía Almejas) and depth zonation within Bahía Almejas (Environmental Systems Research Institute 2002a, b). A 1998 nautical chart produced by the National Imagery and Mapping Agency (NIMA) was scanned and georeferenced to create a derivative digital file. Bathymetry contours were digitally transcribed from this file in ArcView® v3.3 to create contour polygons at 10 m intervals for Bahía Almejas and at 20 m for the adjacent offshore region. Spatial analysis was then performed to estimate depth–specific area within Bahía Almejas. Similarly, distinct polygons were created for each BMLC region using the Mexican states shapefile available from ArcGIS® v8.2 and subsequently used to estimate region–specific area.

Sediment samples were collected in Bahía Almejas on 22 and 23 August 1999. Thirty sampling locations were randomly selected and were then grouped based on relative proximity to facilitate efficient data collection. Only the first three groups, representing seven locations (Fig. 2), were sampled as a result of logistic problems encountered during fieldwork. Three replicate sediment samples were collected manually at each location, using SCUBA when necessary, with cores constructed from coffee cans of 10.0 cm diameter and 13.7 cm height. Penetration of most cores was 8–10 cm.

Sediment samples were analyzed for grain size using procedures and protocol modified from Folk (1974). Sediments were desiccated for 24 hours at 60°C in a drying oven, weighed, and visually inspected. Samples containing mud were additionally processed by adding 50 ml of de–ionized water and a 10 ml solution of 50 g/L dishwashing soap to facilitate de–flocculation of clays. These clay–enriched samples were then placed on a rotary table at 110 rpm for 24 hours to disaggregate clay clasts and wet sieved through a 38 μm (6ϕ) screen. The remaining fraction (> 38 μm) was dried for an additional 24 hours and re–weighed. The difference between original and post–processing weights was used to determine the weight of mud removed from the samples.

The retained sediment (> 38 μm) for each sample was shaken in a mechanical Roto–Tap for 15 minutes to separate clasts. Sets of three incrementally finer sieves (>125 μm, >63 μm, and >38 μm) were used were used to sort sediment by grain size. Based on the relative weight of each grain size category, samples were classified using the Wenthworth sedimentary grade scale (Wentworth 1922). Estimates of sediment sorting, a measure of the uniformity of sediment clast size, were determined visually based on an illustration from Boggs (2001). The predominant mineral grains of the sediment samples were identified using a dissecting microscope.

Results and Discussion

Physical description and bathymetry

The BMLC is located on the Pacific coast of Baja California Sur, beginning ~900 km southeast of the U.S./Mexican border (Fig. 1). It is the largest embayment on the west coast of the Baja peninsula, spanning between 24° 20′ and 25° 44′ N and 111° 27′ and 112° 15′ W, a total surface area of ~1409 km^2. The BMLC is bounded by a series of islands and sand bars that parallel the coast and divide it into three well–defined regions (Alvarez–Borrego et al. 1975): 1) a northwest zone of canals and mangrove–lined channels (~299 km^2); 2) a central zone, consisting of Bahía Magdalena (~696 km^2); and 3) a southeast zone, composed of Bahía Almejas (~414 km^2).

The northwest region, sometimes referred to as the "Zona de Canales," is bordered by Isla Magdalena to the west and connects to the Pacific from three northern entrances: Boca la Soledad, Boca Santo Domingo, and Boca las Animas (Fig. 1). Although some authors consider this region to terminate at either Boca Santo Domingo or Boca las Animas, for the purposes of this review, the Zona de Canales was considered the entire contiguous inshore area north of Bahía Magdalena. The interior canals and channels that constitute the great majority of this region are narrow (0.2–2 km) and shallow (mean depth 3.5 m; Alvarez–Borrego et al. 1975). Maximum depth (17.8 m) is located in an outer channel to the extreme southwest, near the Bahía Magdalena boundary (~24.81° N, 112.17° W; NIMA, 1998). Because of the physical characteristics of this region and tidal fluctuations, the morphology of the littoral zone is irregular and temporally variable.

Isla Magdalena (to the west) and Isla Santa Margarita (to the south) border Bahía Magdalena, the largest of the three regions (Fig. 3). This embayment is connected to the Pacific Ocean by a pronounced, central channel (Boca Entrada, ~5.5 km wide) that reaches a depth of 38 m. Bahía Magdalena is joined to Bahía Almejas by the deep (maximum depth ~30 m) and relatively narrow (~2.5 km) Canal Gaviota, whereas its

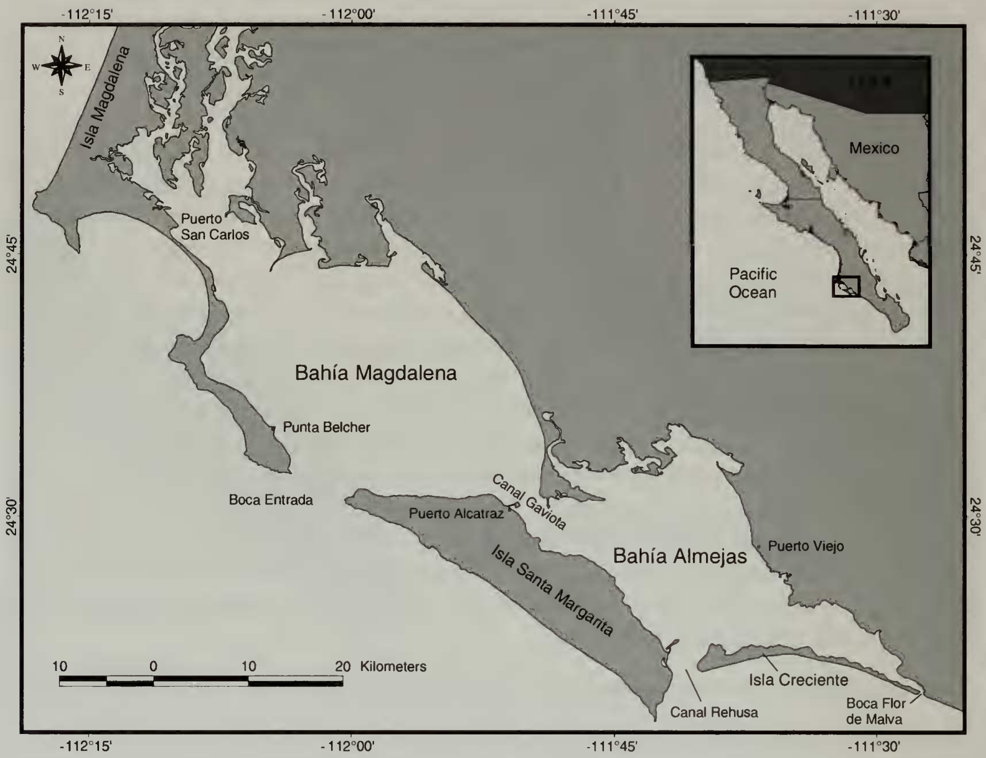

Fig. 3. Bahía Magdalena and Bahía Almejas, located in the central and southeastern part of the Bahía Magdalena lagoon complex. Primary locations and areas of interest are depicted.

connection to the Zona de Canales is shallower (< 1–12 m) and wider (~4.5 km; Alvarez–Borrego et al. 1975; NIMA 1998). Deep water (> 30 m) is confined to the western region of the lagoon, inshore of Isla Magdalena, with a maximum depth of 44 m located off Punta Belcher (~24.60° N, 112.06° W; NIMA 1998; Fig. 3). Much of Bahía Magdalena, including most of the northern and eastern regions, is < 10 m, with extensive intertidal areas in the extreme northern portions (Alvarez–Borrego et al. 1975; NIMA 1998).

Bahía Almejas is separated from the Pacific Ocean by Isla Santa Margarita, which forms its western border, and Isla Creciente, which forms its southern border (Fig. 3). The shallow, southeastern portion of Bahía Almejas is sometimes referred to as Bahía Santa Marina. Open sea connections from Bahía Almejas are present just east of Isla Creciente through Boca Flor de Malva and west of Isla Creciente through Canal Rehusa. Both conduits are narrow and shallow (0.2–2 km, < 1–14 m) with strong currents, and do not typically permit navigation (Alvarez–Borrego et al. 1975; NIMA 1998; pers. obs.).

The maximum depth of Bahía Almejas is 27.5 m (~24.46–24.47° N, 111.73° W), but most of the region is considerably shallower (NIMA 1998). The deepest portions are located inshore of Isla Santa Margarita, and extend northwest to the Bahía Magdalena boundary (Fig. 2). Depths > 20 m are confined to these regions and constitute only ~6.5% (27 km^2) of the Bay floor area, based on surface area extrapolations. Depths of 10–20 m occur in the central and northwest regions, surrounding the deepest isobaths and in association with Canal Rehusa. Approximately 22.5% (93 km^2) of Bahía Almejas overlies this depth range. The great majority of the lagoon is < 10 m (~71.0%, 294 km^2)

and much of the northern and southeastern regions are exposed at low tides (Alvarez–Borrego et al. 1975; pers. obs.).

Geology and tides

As a result of historic subduction and subsequent transform (NW–SE) faulting along the Pacific coast of the Baja California peninsula, the continental shelf is typically narrow (< 20 km), but widens to 50–70 km in association with most central and southern embayments (Inman and Nordstrom 1971; Spencer and Normark 1989; Ibarra–Obando et al. 2001; Sedlock 2003). Offshore of the BMLC, the continental shelf is narrowest off Bahía Magdalena, with the shelf break (~–200 m) located only ~19 km from Boca Entrada (NIMA 1998). The sea floor of the Pacific Baja continental shelf is composed of heavily faulted volcanic and sedimentary rock that is either exposed or thinly covered with recent (Quaternary) sediment (Lankford 1977; Frizzell 1984). Within the last ~80,000 years, depressions were formed throughout the inshore parts of this region from differential combinations of tectonic, sedimentary, and hydrological processes (Lankford 1977). Rising sea level during the last ~20,000 years filled these depressions and transformed them into modern lagoons and embayments (Lambeck and Chappell 2001).

Based on their patterns of origin, Bahía Magdalena and Bahía Almejas are considered tectonic structural lagoons whereas the Zona de Canales is a Gilbert de Beaumont barrier lagoon (Lankford 1977). Tectonic structural lagoons characteristically consist of depressions and/or barriers produced by faulting, folding, or vulcanism that are independent of sea level history. The typical oval form and irregular bathymetry are consistent, with only slight modifications caused by localized run–off. In contrast, Gilbert de Beaumont barrier lagoons are situated between the mainland coast and bordering sand barriers, and were formed within the last 5,000 years at current sea level. Tidal action, storm surges, and aeolian sands modify the form and bathymetry of these shallow, elongate lagoons. Both Bahía Magdalena and Bahía Almejas were formed by northwest–southeast faulting along the Tosco–Abreojos fault zone, with the upthrown side of the fault zone forming Isla Santa Margarita and Isla Magdalena (Spencer and Normark 1979; Blake et al. 1984). No specific scenario has been proposed for the origin of the Zona de Canales.

The sedimentary composition of the BMLC consists primarily of fine to very fine sand, with appreciable amounts of lime and clay (Félix–Pico et al. 1986; Gutiérrez–Sánchez 1997). Rocky substrate is uncommon and mainly limited to the western margins of Bahía Magdalena and Bahía Almejas where reefs are present off Isla Magdalena and Isla Santa Margarita (pers. obs). Local current patterns are largely responsible for spatial differences in grain size and sorting. Generally, very fine sand is found in the deepest portions of the Bays; fine, very well sorted sand is found at moderate depths; shallow waters at the margins of the Bay mouths are composed of moderately sorted, fine sand; and medium–sized sand is located in the channels, shallow water regions, and at the margins of sand bars. Coarse sand is confined to Canal Gaviota (Félix–Pico et al. 1986). The Zona de Canales is composed of sands, ranging from ~60% medium and coarse sand near Boca Santo Domingo to fine sand in association with weak tidal currents south of Boca la Soledad (Phleger and Ewing 1962). Lime and clay are primarily restricted to Bahía Almejas, where lime is found throughout the central region and clay is also abundant in deep water and off central Isla Santa Margarita (Gutiérrez–Sánchez 1997).

Cores collected in Bahía Almejas support the general sedimentary pattern previously described for this region. Samples located in deep water (> 20 m) were composed of

Table 1. Grain size (mm), classification, sorting, and dominant clast of sediment samples collected in Bahía Almejas during August 1999. Sample collection locations are displayed in Fig. 2.

Sample	Grain size	Classification	Sorting	Dominant clast	Description
1	0.063–0.125	Very fine sand	Very well	60–70% quartz	Quartz arenite sand
2	0.063–0.125	Very fine sand	Very well	60–70% quartz	Quartz arenite sand
3	0.063–0.125	Very fine sand	Very well	60–70% quartz	Quartz arenite sand
4	0.063–0.125	Very fine sand	Very well	60–70% quartz	Quartz arenite sand
5	0.038–0.063	Coarse silt	Moderate	60–70% quartz	Quartz silt w/ shell and organic fragments
6	0.038–0.063	Coarse silt	Moderate	60–70% quartz	Quartz silt w/ shell and organic fragments
7	0.038–0.063	Coarse silt	Moderate	60–70% quartz	Quartz silt w/ shell and organic fragments

moderately sorted coarse silt (38 μm–63 μm) with shell and organic fragments, whereas those at shallow depths (< 10 m) were composed of very well sorted very fine arenite sand (63 μm–125 μm; Table 1). The dominant mineral was quartz (60–70%; Table 1). All samples contained < 10% medium and fine silt (< 38 μm). The presence and contribution of lime and arsenic, which is present in elevated concentrations, especially at the transition between Bahía Magdalena and the Zona de Canales (Shumilin et al. 2005), were not determined.

The tidal regime (24.8 hours) in the BMLC is mixed semidiurnal, with periods of higher high water followed by those of lower low water, a condition that produces greater current velocities during ebb tides (Lankford 1977; Obeso–Nieblas et al. 1999). The tidal range is considerable and varies throughout the region, measuring 1.19 m at Canal Rehusa, 1.46 m at Puerto Alcatraz, and 1.70 m at Puerto San Carlos (Fig. 3; NIMA 1998; Obeso–Nieblas et al. 1999). Tidal currents are an important source of energy for lagoon systems, especially in canals and channels, for erosion and transportation of sediment, and for mixing of waters (Lankford 1977; Guerrero et al. 1988). Greatest current velocities occur during ebb lower low water at the mouth of Bahía Magdalena (1.09 m/s), and are similar at Canal Gaviota (0.52 m/s) and Canal Rehusa (0.50 m/s; Fig. 3; Obeso–Nieblas et al. 1999). These differential greater ebb velocities flush suspended sediment and slow or inhibit the sedimentary infilling process that is typical to most lagoons (Postma 1965; Obeso–Nieblas et al. 1999). Whereas current velocities are considerable in channels and canals, they are slight in the other regions of the BMLC, with nearly quiescent water in the central part of Bahía Almejas (Obeso–Nieblas et al. 1999). The general flow pattern at flood tides results in an influx of water to Bahía Almejas both through the Canal Gaviota and Canal Rehusa, a situation that reverses at ebb tides.

Hydrology and climate

The California Current System (CCS), which represents the eastern limb of the anticyclonic North Pacific gyre, has a pronounced effect on the structure and function of coastal upwelling off the Baja California Peninsula and the climate and hydrology of regional lagoonal systems (Lynn and Simpson 1987; Ibarra–Obando et al. 2001). The CCS consists of the California Current, a surface current (0–300 m deep) that extends to 900 km offshore and transports cool, low salinity, oxygen–rich water towards the North Equatorial Current, and the California Countercurrent (Countercurrent), a northward flowing nearshore (typically within 150 km) current of contrasting characteristics (Lynn and Simpson 1987). In the spring and summer, the Countercurrent is covered by southward flowing surface waters and typically occurs at depths of 200–500 m. In fall and winter, the Countercurrent reaches nearshore surface waters in California where the flow is often poleward (Ibarra–Obando et al. 2001).

Off the Baja California Peninsula, the core of the California Current is especially close to shore (< 200 km) and the Countercurrent is less pronounced. Although there is strong seasonal variability in equatorward flow (maximum speed = 20 cm/s in March, April), poleward flow is very weak or nonexistent in northern and central regions and typically confined to winter months in southern regions (Lynn and Simpson 1987). However, as a result of latitudinal temperature gradients, the mean annual sea surface temperature and variability increase greatly from northern California (12° ± 3.5°C) to offshore of Bahía Magdalena (23° ± 10°C). The impact of El Niño Southern Oscillation (ENSO) events on the CCS include enhanced Countercurrent intensity and width, a dominant cyclonic circulation pattern, reduced upwelling, and intensive warming of the upper mixed layer (Lynn et al. 1995).

The offshore region adjacent to the BMLC is considered a wind–driven upwelling system. Brisk northerly and northwesterly winds, created by the gradient between warm, low–pressure inland regions and cool, high–pressure offshore regions, induce offshore transport of surface waters and drive this system (Bakun and Nelson 1977; Ibarra–Obando et al. 2001). The onset and persistence of these winds are influenced by CCS conditions, with strong equatorial flow evident during periods of upwelling and reduced or poleward flow typically associated with the absence of upwelling. Although the most intense period occurs during spring and early summer (March–June), upwelling persists episodically throughout the year (Bakun and Nelson 1977). Variability in the CCS and the timing and intensity of upwelling greatly influences the physical characteristics (e.g., temperature, salinity, dissolved oxygen) of coastal lagoon systems.

Surface temperature within the BMLC is consistently greater than that of adjacent ocean waters and is spatially and temporally variable. Minimum monthly temperatures (20.3 ± 0.5°C, mean and standard deviation), averaged throughout this region from data collected in 1913, 1974–1975, and 1981–1998, typically occur during January or February. Maximum values are reached in August (26.6 ± 1.2°C) and September (26.9 ± 1.0°C; Lluch–Belda et al. 2000). In general, elevated temperatures are located in the interior portions of the embayments and cooler waters are found near the open sea connections. This situation is most evident in Bahía Magdalena during periods of coastal upwelling, when cool oceanic water is advected into the Bay (Bakun and Nelson 1977; Lluch–Belda et al. 2000). The BMLC is warmer than the adjacent Pacific Ocean during all months of the year, with the smallest differences (< 0.7°C) occurring between October and January and the greatest (2.6–3.7°C) between March and August. During ENSO conditions, temperatures in these embayments can reach > 31°C with anomalies > 6°C (Lluch–Belda et al. 2000).

Bahía Almejas (23.1 ± 2.6°C) and the Zona de Canales (23.1 ± 3.0°C) have similar average annual temperatures but Bahía Magdalena is slightly cooler (22.3 ± 2.5°C), with characteristics that are more oceanic (Lluch–Belda et al. 2000). The highest average monthly temperatures are recorded during August in shallow regions of the Zona de Canales (> 29.0°C) and the lowest during May (< 18.0°C) in west–central Bahía Magdalena, a region of upwelling (Alvarez–Borrego et al. 1975; Lluch–Belda et al. 2000). In Bahía Almejas, temperatures remain consistent (20.3–21.5°C) between December and May, increase slightly during June (22.3°C) and then remain high (> 25.0) from July to

October, peaking in August (27.7°C). November (23.2°C), like June, represents a transition month. This temporal pattern is also evident in the Zona de Canales, but differs in Bahía Magdalena, where the coldest temperatures coincide with upwelling in April and May. Monthly average temperature is highly uniform throughout Bahía Almejas but more variable in the other regions, especially during June and July (Lluch–Belda et al. 2000).

Hydrologic conditions in the BMLC are hypersaline throughout the year as a result of low precipitation, the typical absence of fresh water input, and a high rate of evaporation. The distribution of surface salinity is largely dependent on spatial temperature and depth differences, with values lowest near open sea connections and highest at shallow, interior locations. Dissolved oxygen content, however, is strongly correlated with primary productivity and remains elevated throughout the year (Alvarez–Borrego et al. 1975). The Zona de Canales is the most variable region because of its shallow bathymetry and the differential influence of ocean waters between the northern and southern outlets. In this region, surface salinity increases along a consistent north–south gradient, reaching highs (39.2‰) in July and August and lows (34.1‰) in March. Dissolved oxygen content ranges from 3.9 ml/l during July and August to 5.3 ml/l during March. Percent saturation is consistently high and varies from 83 to 107 (Alvarez–Borrego et al. 1975). In Bahía Magdalena, salinity values are less variable than in the Zona de Canales, ranging from 34.0–36.0‰ with consistently lower values measured in the western part of the Bay. Dissolved oxygen content is typically > 5.0 ml/l (> 100% saturated) but ranges from lows of 2.74 ml/l (~60% saturated) during June in northwest nearshore waters, to highs of > 6.0 ml/l (~120% saturated) during July and August in west–central nearshore waters (Alvarez–Borrego et al. 1975). In Bahía Almejas, surface salinity values are relatively uniform throughout the year, ranging from lows of 34.0‰ in the west–central region, to highs of 35.1‰ in the northeast. Dissolved oxygen content is typically 5.0 ml/l or greater (> 100% saturated) with little spatial or temporal variation (Alvarez–Borrego et al. 1975). Both maximum (8.5) and minimum (7.4) pH values for the BMLC were recorded in the Zona de Canales during June and October, respectively. The pH of both Magdalena and Bahía Almejas is less variable, ranging from 8.0–8.5 (Alvarez–Borrego et al. 1975).

The BMLC region is part of the Sonoran Desert, and the climate characteristically varies from temperate to hot and is very dry (Garcia 1973; MacMahon 1997). Mean annual air temperature is ~22°C, and ranges from 12° in December and January to 30° in July and August (Garcia 1973; National Climatic Data Center 1994). Precipitation in this region falls irregularly during two consecutive rainy periods, from July to October and November to February, but is mainly restricted to summer and early fall (Lankford 1977; Salinas–Zavala et al. 1990). During this time, tropical storms typically originating in the Gulf of Tehuantepec may reach the BMLC (Lankford 1977). The average annual rainfall in BCS is 160 mm, although interannual values may differ substantially (from 46–608 mm) as a result of the variable intensity of summer storm seasons (Ibarra–Obando et al. 2001). Annual precipitation values of 1–14 mm have been reported for the northern BMLC (Alvarez–Borrego et al. 1975), but these amounts probably actually represent centimeters. There is no permanent river input in the BMLC, but rather periodic inputs during infrequent rainy periods. Run–off in this region is therefore negligible (Guerrero et al. 1988; pers. obs).

Regional marine biogeography

The west coast of North America has been divided into biogeographic regions, or faunal provinces, by many authors, often differing somewhat in terminology and boundaries. Most of these authors, however, consider the BMLC to represent a transition zone between warm–temperate and tropical species (e.g., Hubbs 1960; Briggs 1974; Brusca 1980; Allen and Robertston 1994). According to a modified version of Briggs' (1974) classification system, the BMLC is situated at the boundary between the San Diego Province of the temperate California Region and the Cortez Province of the tropical East Pacific Region (Hastings 2000). The San Diego Province, also referred to as the California Province (McLean 1969; Brusca 1980), ranges north to Point Conception, California (34° 10′ N). The Cortez Province extends around the southern tip of Baja California Sur, and continues through the Gulf of California to Topolobampo (25° 36′ N; Hastings 2000). Some authors consider the Cortez Province to be incorporated within larger Mexican (to the Gulf of Tehuantepec) or Panamic Provinces (to Peru; Hubbs 1960; Brusca 1980; Aguilar–Palomino et al. 2001).

The faunal break between the San Diego and Cortez Provinces is neither abrupt nor consistent as a result of spatial and temporal discontinuities in water temperature and current regimes (Hubbs 1948, 1960; Hewitt 1981; McLain and Thomas 1983). Many tropical species extend north of the BMLC for a considerable distance, inhabiting shallow, protected bays and inlets, whereas warm–temperate species are found in nearshore coastal regions and cool–temperate species are associated with upwelling areas (Garth 1960; Hubbs 1960). Upwelling regions and associated cold–temperate fauna typically reach their terminus offshore of the BMLC and warm–temperate species decline abruptly south of this region (Hubbs 1960; Aguilar–Palomino et al. 2001, Ibarra–Obando et al. 2001). In contrast, Punta Eugenia (27° 50′ N) is considered the northern limit of many tropical taxa, including fishes (Hubbs 1960; Hastings, 2000), crabs (Garth 1960), bryozoans (Soule 1960), and molluscs (Hall 1964; Valentine 1966). Based on these factors, the entire region between the BMLC and Punta Eugenia can be considered a transitional zone of discontinuous overlap between temperate (San Diego) and tropical (Cortez) fauna (Brusca 1980).

Littoral vegetation and marine algae

Along the Pacific coast of BCS, between ~27° N and ~24° N, mangroves replace salt marsh species (e.g., *Spartina foliosa*, *Sarcocornia pacifica*) as the dominant littoral vegetation (Ibarra–Obando et al. 2001). White (*Laguncularia racemosa*), red (*Rhizophora mangle*), and black (*Avicennia germinans*) mangrove species are present throughout the BMLC (Nienhuis and Guerrero–Caballero 1985; Gárate–Lizárraga and Siqueiros–Beltrones 1998; pers. obs.). In Bahía Magdalena and Bahía Almejas, these species occur in isolated littoral forests in contrast to the more abundant, but smaller morphs that line the canals to the northwest (Gárate–Lizárraga and Siqueiros–Beltrones 1998). Mangroves provide habitat for a great variety of invertebrates and fishes in the BMLC that either use their roots for shelter, or inhabit inlets that are fringed by this vegetation (pers. obs.).

More than 130 species of macroalgae have been recorded from the BMLC (Sánchez–Rodríguez et al. 1989). In general, as latitude decreases along the Pacific coast of the Baja California peninsula, tropical and subtropical red algae (Rhodophyta) become abundant (Ibarra–Obando et al. 2001). This group is locally dominant, with 88 species and 18 families representing an estimated 66.6% of total macroalgal biomass (Sánchez–Rodríguez et al. 1989). The families Corallinaceae (N = 20), Rhodomelaceae (N = 16), and Ceramiaceae (N = 14) are most speciose (Sánchez–Rodríguez et al. 1989). In contrast to Rhodophyta, brown algae (Phaeophyta) declines in abundance and species richness as latitude along the Pacific coast of the Baja peninsula decreases (Aguilar–Rosas and Aguilar–Rosas 1993). Twenty–two species and six families of Phaeophyta are known from the BMLC, contributing a measured 16.7% to total macroalgal biomass. Among brown algas, the family Dictyotaceae (N = 11) is most speciose (Sánchez–Rodríguez et al. 1989). Green algae (Chlorophyta) constitutes an estimated 16.7% of macroalgal biomass in the BMLC, with seven families and 22 species (Sánchez–Rodríguez et al. 1989). Most Chlorophyta species belong to the families Ulvaceae (N = 7) and Codiaceae (N = 6; Sánchez–Rodríguez et al. 1989). Eelgrass (Chlorophyta: *Z. marina*), the most abundant subtidal macrophyte in coastal lagoons of the Baja California peninsula, reaches its southern limit but exhibits its highest regional flowering effort at the BMLC (Riosmena–Rodríguez and Sánchez–Lizaso 1996; Santamaría–Gallegos et al. 2003). The BMLC also represents the southernmost occurrence of surfgrass (*P. torreyi*; Riosmena–Rodríguez and Sánchez–Lizaso 1996).

Phytoplankton

The BMLC is a region of high primary productivity throughout the year, with maximum reported microphytoplankton densities of 1,500,000 cells/liter and maximum reported nanoplankton densities of 791,760 cells/liter (Alvarez–Borrego et al. 1975; Nienhuis and Guerrero–Caballero 1985; Gárate–Lizárraga et al. 2001). There are two general patterns in phytoplankton abundance, a period of high densities from November to May, corresponding to a cool–water period, and a period of relatively low densities from June to October, corresponding to a warm–water period (Nienhuis and Guerrero–Caballero 1985; Gárate–Lizárraga et al. 2001). Phytoplankton abundance is similar in surface and subsurface waters (Gárate–Lizárraga et al. 2001). Bahía Magdalena is the most productive of the three BMLC regions, primarily because of the advection of upwelled oceanic water. Especially between March and June, advection infuses the west–central region of Bahía Magdalena with nutrients during flood tides, resulting in increased photosynthetic activity and the export of elevated levels of dissolved oxygen and chlorophyll *a* to adjacent oceanic waters during ebb tides (Alvarez–Borrego et al. 1975; Acosta–Ruiz and Lara–Lara 1978; Guerrero et al. 1988).

The structure and abundance of the local phytoplankton assemblage are extremely variable both temporally and spatially, and are determined by a complex interaction of hydrological factors (Gárate–Lizárraga et al. 2001). The presence of nutrient–rich water pockets, either as a result of upwelling, mineralization of allochthonous inputs from mangroves (especially in eastern and north–western Bahía Magdalena), or tidal mixing are some of the primary factors that determine distribution and density of phytoplankton (Nienhuis and Guerrero–Caballero 1985; Gárate–Lizárraga and Siqueiros–Beltrones 1998). According to studies conducted by Nienhuis and Guerrero–Caballero (1985) during 1980 and 1981 and Gárate–Lizárraga and Siqueiros–Beltrones (1998) during 1982–1986, microphytoplankton is the dominant phytoplankton component with nanoplankton representing a minor fraction, except during warmest water periods. Similar to previous studies, Gárate–Lizárraga et al. (2001) reported maximum abundance and microphytoplankton diversity during 1988–1989 at the end of the cool season (May) and relatively low mean values in concurrence with warm periods. However, Gárate–Lizárraga et al. (2001) determined that nanoplankton (primarily phytoflagellates, coccolithophorids, and naviculoid diatoms) contributed most to total phytoplankton abundance and was especially dominant in winter months. These inconsistent results are probably a consequence of the extremely high temporal and spatial variability in BMLC hydrological parameters. Therefore, there is not likely a predictably characteristic phytoplankton assemblage, but rather a dynamic mosaic of available flora.

At least 87 genera and 277 taxa of phytoplankton have been reported from the BMLC (Gárate–Lizárraga and Sisqueiros–Beltrones 1998; Gárate–Lizárraga and Verdugo–Díaz 2001). Within the microphytoplankton, diatoms [especially *Chaetoceros* spp. (N = 27), *Rhizosolenia* spp. (N = 15), and *Coscinodiscus* spp. (N = 9)] are the dominant species, whereas, nanoplankton is primarily composed of Chrysophyceae and Cryptophyceae (Nienhuis and Guerrero–Caballero 1985; Gárate–Lizárraga and Siqueiros–Beltrones 1998). The species composition and diversity of the phytoplankton assemblage vary throughout the year in accordance with changing hydrological conditions (Nienhuis and Guerrero–Caballero 1985; Gárate–Lizárraga and Siqueiros–Beltrones 1998). Diatoms are the most diverse (N = 171) and abundant taxa, followed by dinoflagellates (N = 84), silicoflagellates (N = 5), and cyanobacteria (N = 5; Gárate–Lizárraga 1992). Between 22–27 diatom species that are widely distributed along the coastal Baja California peninsula are responsible for most of the phytoplankton dynamics. Phytoplankton diversity is greatest in association with the oceanic region of Bahía Magdalena and lowest in association with episodic, widespread blooms of different species throughout the year (Gárate–Lizárraga and Sisqueiros–Beltrones 1998). Diatoms generally increase in abundance during periods of warm–water, whereas dinoflaggelates are typically more abundant in association with cooler water (Gárate–Lizárraga and Siqueiros–Beltrones 1998; Ibarra–Obando et al. 2001), although Gárate–Lizárraga et al. (2001) reported an opposite pattern. El Niño Southern Oscillation warming causes diminished species richness, diversity, and abundance of phytoplankton in this region, the effects of which may linger for one or more years (Nienhuis and Guerrero–Caballero 1986; Gárate–Lizárraga and Siqueiros–Beltrones 1998).

Zooplankton

The BMLC zooplankton assemblage is dominated by copepods, which comprise 50–90% of total zooplankton biomass throughout the year (Palomares–García 1992; Palomares–García and Gómez–Gutiérrez 1996). At least 79 species and 35 genera have been reported, with calanoids (*Acartia lilljeborgii*, *A. clausi*, and *Paracalanus parvus*) typically representing > 75% of total copepod biomass (Palomares–García 1992; Palomares–García and Gómez–Gutiérrez 1996). This situation is characteristic of other coastal lagoons, where one or few species are numerically dominant, and in contrast to the condition in adjacent coastal waters where a more diverse and less abundant assemblage is common (Margalef 1969). Cyclopoid copepods (i.e., *Corycaeus* spp. and *Oithona* spp.) are present in relatively low to moderate numbers throughout the year. Only one species of harpacticoid copepod, *Euterpina acutifrons*, is common to the BMLC (Palomares–García 1992). Although copepods dominate zooplankton biomass, they do not influence total plankton abundance, because phytoplankton biomass is considerably greater throughout the year.

There is a well–defined seasonal pattern of copepod diversity and species succession in the BMLC that is closely related to changes in hydrology, especially the direction and intensity of the California Current. The copepod assemblage is less diverse during cool–water periods (winter and spring), when strong southward flow is dominant and the fauna is largely restricted to temperate species. During warm–water periods (summer and fall), when southward flow is weak or reversed, tropical species also become prevalent and diversity increases (Palomares–García 1992; Palomares–García and Gómez–

Gutiérrez 1996; Palomares–García et al. 2003). Locally, the greatest diversity is typically associated with the assemblage at the mouths of Bahía Magdalena and Bahía Almejas, where neritic (e.g., *P. parvus*, *Calanus pacificus*) and oceanic species predominate, especially during periods of upwelling. Minimum diversity values correspond to high densities of *Acartia* spp. (Palomares–García 1992; Palomares–García and Gómez–Gutiérrez 1996). This is especially evident of the typical summer condition in Bahía Almejas, where *A. lilljeborgii* is overwhelmingly dominant (Palomares–García 1992). Generally, resident species such as *Acartia* spp. are rarely or never found outside the BMLC, exhibit the strongest seasonal variations, and comprise 50–85% of copepod abundance (Palomares–García 1992; Palomares–García and Gómez–Gutiérrez 1996). The seasonal succession of the copepod assemblage, most evident in the replacement of *P. parvus* during cool–water periods by *A. lilljeborgii* during warm–water periods, is predictable and stable.

This pattern of copepod succession remains consistent even under ENSO conditions, although the relative abundance of tropical species increases and the tropically distributed *A. tonsa* may replace the more temperate *A. clausi* (Palomares–García and Gómez–Gutiérrez 1996; Palomares–García et al. 2003). These characteristics are in stark contrast to those of the phytoplankton assemblage, which is highly variable both intra– and interannually (Nienhuis and Guerrero–Caballero 1986; Gárate–Lizárraga 1992). The permanence of a defined seasonal pattern of relative abundance suggests that the BMLC copepod assemblage is rather stable and that the dominant taxa are highly adaptable to changing environmental conditions.

Chaetognaths are also common components of the BMLC zooplankton assemblage. Of 10 *Sagitta* species reported from the BMLC, *S. euneritica* is the most abundant throughout the year, numerically comprising between 82% (fall and winter) and 95% (spring and summer) of all chaetognaths (Cota–Meza et al. 1992). S*agitta enflata* is the next most abundant species, followed by *S. minima*, which is primarily observed in association with upwelled water at the mouth of Bahía Magdalena from January to July. A tropical assemblage is typically present in relatively small numbers (3.6%) during the fall (Cota–Meza et al. 1992). Greatest overall densities are reported from Bahía Almejas during winter (6024/10 m^2), spring (1811/10 m^2), and summer (2469/10 m^2), and from Bahía Magdalena during fall (7334/10 m^2; Cota–Meza et al. 1992). The Zona de Canales exhibits the lowest abundance in all seasons.

Immature crabs are also consistent seasonal components of the BMLC zooplankton assemblage. Pelagic red crabs (*Pleuroncodes planipes*) use tidal currents to move between the outer coast and the BMLC, vertically migrating to facilitate advection (Robinson and Gomez–Aguirre 2004). Annual mass strandings of this anomuran species are commonly observed on eastern shores of Isla Magdalena and Isla Santa Margarita between April and June. During this time, primarily juvenile *P. planipes* are advected into Bahía Magdalena with upwelled water and sometimes stranded during ebb tide by peripheral currents, which carry them into the surf zone instead of flushing them from the Bay (Aurioles–Gamboa et al. 1994). Zoea of the dominant local blue crab (*Callinectes bellicosus*) are most abundant in the BMLC during August, when the vast numerical majority (89%) have been observed (Sánchez–Ortiz and Gómez–Gutiérrez 1992). During this time, gravid females migrate from shallow water regions to deeper waters near the mouths of Bahía Magdalena and Bahía Almejas, where larvae are hatched and carried out of the Bays during ebb tides. Juveniles later recruit back to the BMLC at the culmination of their pelagic phase (Sánchez–Ortiz and Gómez–Gutiérrez 1992).

Ichthyoplankton

The ichthyoplankton assemblage in the BMLC has been studied both temporally and spatially with somewhat inconsistent results. Based on samples collected throughout the BMLC in October, March, June, and July/August of 1973–1974, Castro–Barrera (1975) identified larvae of 32 teleost families with Gobiidae and, to a far lesser extent Engraulidae, present in greatest abundance. In addition, clinids, serranids, sciaenids, pomadasyids, and pleuronectiformes were noted at lower abundance. Studies conducted in the same regions during January, February, May, and September of 1989, however, identified larvae belonging to 24 families with Gobiidae (especially *Gillichthys y–cauda*) as the dominant taxa numerically (62.4%) followed by Gerreidae (15.6%) and Clupeidae (especially *Sardinops sagax*, 10.5%). In addition, haemulids (2.2%), blenniids (2.2%), and pleuronectiforms (2.1%) were present in lower abundance (Funes–Rodríguez et al. 1998). These rather incongruous findings are likely because of: 1) different oceanographic conditions present during these studies resulting in a variable spawning assemblage and differential spawning periodicity; and/or 2) temporal changes in the local ichthyofaunal assemblage. However, some patterns are evident. In the inner portions of the BMLC, larvae of resident taxa (e.g., Blenniidae, Gobiidae, Gerreidae, Pleuronectiformes) occur throughout the year in association with relatively high temperatures and zooplankton biomasses. At the mouth of Bahía Magdalena, larval engraulids and clupeids are present in association with lower temperatures and zooplankton biomasses. Temporal characteristics of these groups are inconsistent between studies and therefore not reported (Castro–Barrera 1975; Funes–Rodríguez et al. 1998).

Benthic invertebrates

The marine invertebrate assemblage of the BMLC consists primarily of a tropically derived fauna (Garth 1960; Brusca 1980). However, because this region is a transition zone for many taxa, local species richness and diversity are quite substantial and temperate forms, though relatively rare, are not uncommon (Bertsch 1993; Emilia–González 1993; Hendrickx 1993). This situation is well exemplified by the local brachyuran crab fauna. Of 24 spider crabs (Majidae, Parthenopidae) and 10 cancrid crabs (Portunidae, Cancridae, Xanthidae) noted in Bahía Magdalena and Bahía Almejas, only eight species range farther north than San Ignacio Lagoon (Garth 1960). For grapsid crabs (Grapsidae, Ocypodidae), Bahía Magdalena represents the northern extent of two mangrove associated species (*Goniopsis pulchra*, *Sesarma magdalenense*) and Bahía Almejas the southern extent of the fiddler crab, *Uca crenulata* (Garth 1960). It is noteworthy that the most northerly occurrence of these tropical and subtropical species is in this protected lagoon complex, which is sheltered from the Pacific and contains elevated temperatures. In most cases the nearest unprotected coastal regions harboring these species are more than 500 km to the south (Garth 1960).

Although no complete inventory of the invertebrate fauna exists, the sublittoral benthic macroinvertebrate assemblage of the BMLC has been described. Based on comprehensive spatial and temporal sampling throughout the BMLC, at least 75 species, 50 families, and 64 genera are present (Félix–Pico and García–Domínguez 1993). The taxonomic classification of the 68 most common invertebrate species is as follows: Mollusca (N = 27), Arthropoda (N = 22), Echinodermata (N = 6), Porifera (N = 5), Annelida (N = 4), and Cnidaria (N = 4). The assemblage is dominated by the following species, listed in decreasing order: *C. bellicosus* (crustacean), *Luidia phragma* (echinoderm), *Ascidia interrupta* (ascidian), *Penaeus californiensis* (crustacean), *Sicyonia penicillata* (crustacean), *Loliopsis diomedae* (mollusc), *Obelia plicata* (cnidarian), *Astropecten armatus* (echinoderm), and *Argopecten circularis* (mollusc; Félix–Pico and García–Domínguez 1993). Although all of these species are present throughout the year, many exhibit patterns of seasonal abundance. For instance, *C. bellicosus* numerically constituted 81% of all specimens collected between May and September but only 19% of all individuals between October and February (Sánchez–Ortiz and Gómez–Gutiérrez 1992; Félix–Pico and García–Domínguez 1993). Overall invertebrate abundance is also lower from October to February, possibly because a lower temperature regime is not optimal for the predominantly tropical fauna or because the coinciding loss of perennial algas reduces the amount of available habitat. Spatial heterogeneity was observed within the BMLC invertebrate assemblage, with four distinct species groupings present and well–defined northern (Curva del Diablo, ~24.97°N, −112.15°W) and southern (Puerto Cortés, ~24.48°N, −111.82°W) species extents (Félix–Pico and García–Domínguez 1993). Because sampling was conducted with an epibenthic sled over predominantly soft substrates, several common, commercially important infaunal (e.g., *Crassostrea palmula*, *C. columbiensis*, *C. gigas*) and rock associated (e.g., *H. corrugata*, *H. fulgens*, *P. interruptus*, *P. inflatus*) species were either absent or under–represented in these studies (pers. obs.). Therefore the described assemblage should be considered to represent the dominant macroepibenthic species associated with soft substrates.

Ichthyofauna

Because it is located at a transition zone and includes several habitat types, the BMLC contains a highly diverse ichthyofauna with 315 documented species, corresponding to 92 families and 199 genera (Torres–Orozco and Castro–Aguirre 1992; Castro–Aguirre and Torres–Orozco 1993; Cruz–Agüero et al. 1994; Gutiérrez–Sánchez 1997; Mariano–Meléndez and Villavicencio–Garayzar 1998; Galván–Magaña et al. 2000; Bizzarro, 2005). Of these, 269 species, 171 genera, and 75 families are teleosts. The most speciose families are: Haemulidae (N = 19), Serranidae (N = 17), Sciaenidae (N = 17), and Carangidae (N = 16) (Torres–Orozco and Castro–Aguirre 1992; Galván–Magaña et al. 2000). The faunal assemblage of the BMLC is rather unique when compared with other BCS embayments, but more closely aligned with those of the inner coast (i.e., Bahía de la Paz, Bahía Concepción) than the outer coast (i.e., Laguna San Ignacio, Laguna Ojo de Liebre; Galván–Magana et al. 2000). Among BCS lagoons, only the larger, deeper Bahía de la Paz (N = 384) has greater species richness (Galván–Magana et al. 2000).

Most fishes are tropical and subtropical in origin, but many temperate species are also present (Castro–Aguirre and Torres–Orozco 1993; Gutiérrez–Sánchez 1997; Galván–Magana et al. 2000). The temperate component is not restricted to warm–temperate species of the San Diego province and instead contains a mixture of species with distributions throughout the eastern North Pacific (e.g., Love et al. 2005). These species were likely transported through dispersion via the California Current system, especially during the Wisconsin (early Pleistocene) and earlier ice ages when current patterns and temperate regimes created conditions that favored their establishment (Hubbs 1960; Dawson 1992; Castro–Aguirre and Torres–Orozco 1993). Periods of strong California Current flow and local upwelling continue to seasonally infuse the BMLC with temperate species. Tropical and subtropical elements of the BMLC ichthyofauna are believed to be derived from one of two sources: 1) from remnant populations established as the Baja California Peninsula rifted from the Jalisco region of southwestern Mexico during the Miocene and Pliocene (~4–8 million years ago) and, 2) from the southern Gulf of

California via a Tertiary paleochannel between the BMLC and Bahía La Paz (Castro–Aguirre and Torres–Orozco 1993; Sedlock 2003). Allochthonous fauna are also transported to this region during periods of intense California Countercurrent or North Equatorial Current flow, especially in associated with ENSO conditions (Torres–Orozco and Castro–Aguirre 1992). A very minor component of the tropical ichthyofauna is derived from long distance dispersal, particularly of larval forms, from the Indo–Pacific (Hubbs 1960; Allen and Robertson 1994; Galván–Magaña et al. 2000).

In addition to its great diversity and species richness, the ichthyofauna of the BMLC is temporally variable. Temperature is considered the primary factor affecting the distribution of marine fishes along the Pacific coast of North America and is the main determinant of fish distribution in this region (Hubbs 1948, 1960; Torres–Orozco and Castro–Aguirre 1992; Castro–Aguirre and Torres Orozco 1993). Because the BMLC is located at a faunal boundary, vicissitudes in the CCS greatly affect the species composition and relative abundance of the local ichthyofauna, with temperate species becoming more pronounced in times of strong California Current flow or upwelling and less common during strong Countercurrent flow or during ENSO warming events (Torres–Orozco and Castro–Aguirre 1992; Castro–Aguirre and Torres Orozco 1993; Gutiérrez–Sánchez 1997). The temporally divergent occupation of west–central Bahía Magdalena by the pelagic species *S. sagax* and *Opisthonema libertate* provides a good example of this condition. *Opisthonema libertate* immigrates into Bahía Magdalena as temperatures increase during August, reaches its highest relative abundance from November to January, and then decreases in association with the advection of cooler, upwelled water into the region. In contrast, the more temperately distributed *S. sagax* immigrates into Bahía Magdalena in February and is dominant from April to September, when warmer waters drive it from the region (Casas–Valdez 1987).

Although many species are transient, differential temporal utilization of space enables the persistence of both temperate and tropical residents within the BMLC. Based on monthly trawl surveys of soft bottom regions, Gutiérrez–Sánchez (1997) found fishes of temperate, tropical, and widespread distributions to be among the dominant species numerically (*Etropus crossotus*, *Paralabrax maculatofasciatus*, *Eucinostomus dowii*, *Urobatis maculatus*, and *Ariopsis platypogon*) and by biomass (*P. maculatofasciatus*, *Sphoeroides annulatus*, *Urobatis halleri*, *U. maculatus*, and *E. dowii*). Most temperate species, such as *Paralichthys californicus* and *Pleuronichthys ritteri*, are permanently associated with relatively cool, deeper water regions near Boca Entrada, which remains between 14°C and 18°C even during summer and fall months (Gutiérrez–Sánchez 1997). In winter and spring, tropical species such as *E. dowii*, *Eucinostomus gracilis*, and *A. platypogon* are restricted to the interior regions of the BMLC, where bottom temperatures remain relatively high (15°C to 23°C). During warm–water periods, tropical species increase their distribution and utilize a greater portion of the BMLC. More thermally tolerant species, such as *P. maculatofasciatus*, are widely distributed throughout the year (Gutiérrez–Sánchez 1997). Species richness is greatest between February and July in Bahía Magdalena, when the distinction between cool and warm regions is most pronounced, thereby facilitating the presence of both temperate and tropical species.

Fisheries

Invertebrate fisheries in the BMLC are primarily artisanal and several taxa are harvested. Principal fishery targets include: bivalves (e.g., *Argopecten circularis*, *Crassostrea* spp., *Megapitaria aurantiaca*), crabs (e.g., *C. bellicosus*), lobsters (e.g., *P. interruptus*, *P. inflatus*), shrimps (e.g., *P. californiensis*, *Panaeus stylirostris*), abalones (e.g., *H. fulgens*, *H. corrugata*), and snails (e.g., *Astrea undosa*, *Astrea turbanica*; Flores–Castanon 1980; Ramírez–Rodríguez 1987; Sánchez–Ortiz and Gómez–Gutiérrez 1992; Casas–Valdez et al. 1996; pers. obs.). Mariculture of bivalves (e.g., *Argopecten venticosus*, *Crassostrea gigas*, *Nodipecten subnodosus*) throughout the BMLC and shrimp (e.g., *P. stylirostris*) in southeastern Bahía Almejas is also common (Casillas et al. 1988; Cáceres–Martínez and García–Bustamante 1990; Maeda–Martínez et al. 2000, Koch et al. 2005).

Both pelagic and demersal fishes are targeted in the BMLC. Schooling pelagic fishes such as sardine (*S. sagax*), herrings (*O. libertate*, *Etrumeus teres*), anchovy (*Cetengraulis mysticetus*), and Pacific mackerel (*Scomber japonicus*) support large industrial fisheries (Casas–Valdez 1987; Félix–Uraga et al. 1996; Robinson et al. 2000; Morales–Bojórquez 2002). Artisanal fishermen target demersal teleosts and elasmobranchs (Gutiérrez–Uribe 1987; Ramírez–Rodríguez 1987; Villavicencio–Garayzar 1995). Although no additional studies have been recently published, earlier works indicated that serranids (e.g., *Epinephelus analogus*, *Paralabrax nebulifer*, *Mycteroperca* spp.) were the primary teleost targets, with malacanthids (e.g., *Caulolatilus princeps*), gerreids (e.g., *Eucinostomus argenteus*, *Diapterus peruvianus*), haemulids (e.g., *Haemulon scudderi*, *Pomadasys* spp.), sciaenids (e.g., *Cynoscion parvipinnis*, *Bairdiella icistia*), mugilids (e.g., *Mugil cephalus*, *M. curema*), carangids (e.g., *Trachinotus kennedyi*), lutjanids (e.g., *Lutjanus argentiventris*), and scombrids (e.g., *Scomberomorus sierra*) also taken (Gutiérrez–Uribe 1987; Ramírez–Rodríguez 1987). Information concerning the BMLC artisanal elasmobranch fishery is largely restricted to studies conducted at a single encampment (Puerto Viejo, Fig. 3) in Bahía Almejas at which *Rhinobatos productus* and *Dasyatis dipeterura* were reported as primary targets (Villavicencio–Garayzar 1995; Salazar–Hermoso and Villavicencio–Garayzar 1999; Bizzarro 2005).

Although the natural resources of the BMLC have been exploited for almost a century, resident populations have not greatly expanded and settlements consist primarily of artisanal fishing villages. The two largest towns, Puerto San Carlos (Bahía Magdalena) and Puerto Adolfo Lopez Mateos (Zona de Canales), contain less than 5,000 combined residents (INEGI 2000). However, the BMLC has received a considerable influx of transient fishermen since 1970 (Young 2001), and almost all current settlements were established and used for fishing activities. Several local fishery stocks, including abalone (*Haliotis* spp.), spiny lobster (*Panulirus* spp.), and large demersal teleosts (e.g., serranids) appear to have suffered population declines, largely as a result of unregulated and illegal exploitation (Young 2001). In addition, Puerto Viejo is now abandoned after the apparent serial depletion of large sharks (e.g., *Carcharhinus* spp.) and subsequently rays (e.g., *Rhinobatos productus*; Bizzarro 2005).

Conclusions and Recommendations

The Bahía Magdalena lagoon complex (BMLC) is an important hydrological, biological, and socio–economic center. It is one of the most biologically diverse regions in the coastal Mexican Pacific and is a nursery area for a great variety of invertebrate and vertebrate species, several of which support local fisheries. Because of the documented biological and socio–economic significance of the BMLC and recent declines in several commercially fished species, it is recommended that local fisheries are better monitored and regulated. It is also suggested that increased scientific attention, especially in the form of multi–disciplinary studies detailing community structure, stability, and trophic relationships be focused on the BMLC. This type of research is especially important because potential increases in water temperatures as a result of global climate change may modify this region from a transitional zone of temperate and tropical species to one dominated by tropical biota. A loss or reduction in the occurrence of temperate biota will likely result in decreased diversity and may adversely affect fisheries productivity and nursery function of some species.

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Literature Cited

Acosta–Ruíz, M. and J.R. Lara–Lara. 1978. Resultados fisicoquímicos en un estudio de variación diurnal en el area central de Bahía Magdalena, B.C.S. Cienc. Mar., 5(1): 37–46.

Aguilar–Palomino, B., C. Pérez–Reyes, F. Galván–Magaña, and A. Abitía–Cardenas. 2001. Ictiofauna de la Bahía Navidad, Jalisco, México. Rev. Biol. Trop., 49(1): 173–190.

Aguilar–Rosas, L.E. and R. Aguilar–Rosas. 1993. Ficogeografía de las algas pardas (Phaeophyta) de la Península de Baja California. Pp. 197–206 *in* Biodiversidad marina y costera de México. (Salazar–Vallejo, S.I. and N.E. González, eds.) Com. Nal. Biodiversidad–Centro Investig, Quintana Roo, Mexico.

Allen, G.R. and D.R. Robertson. 1994. Fishes of the tropical eastern Pacific. University of Hawaii Press, Honolulu, HI. 332 pp.

Alvarez–Borrego, B.S., A. Galindo–Bect, and A. Chee–Barragán. 1975. Características hidroquímicas de Bahía Magdalena, B.C.S. Cienc. Mar., 2(2): 94–110.

Aurioles–Gamboa, D., M.I. Castro–González, and R. Pérez–Flores. 1994. Annual mass strandings of pelagic red crabs, *Pleuroncodes planipes* (Crustacea: Anomura: Galatheidae), in Bahía Magdalena, Baja California Sur, Mexico. Fish. Bull., 92:464–470.

Bakun, A. and C.S. Nelson. 1977. Climatology of upwelling related processes off Baja California. CalCOFI, 19:107–127.

Bartsch, P. and H.H. Rehde. 1939. Mollusks collected on the presidential cruise of 1938. Smith. Misc. Coll., 98(10): 1–18.

Beebe, W. and J. Tee–Van. 1941a. Eastern Pacific expeditions of the New York Zoological Society. XXV. Fishes from the tropical eastern Pacific (from Cedros Island, Lower California, South to the Galapagos Island and Northern Peru). Part 2. Sharks. Zoologica, 26:93–124.

——— and ———. 1941b. Eastern Pacific expeditions of the New York Zoological Society. XXVIII. Fishes from the tropical eastern Pacific (from Cedros Island, Lower California, South to the Galapagos Island and Northern Peru). Part 3. Rays, mantas, and chimaeras. Zoologica, 26: 245–280.

Bertsch, H. 1993. Opsitobranquios (Mollusca) de la costa occidental de México. Pp. 253–270 *in* Biodiversidad marina y costera de México. (Salazar–Vallejo, S.I. and N.E. González, eds.) Com. Nal. Biodiversidad–Centro Investig, Quintana Roo, Mexico.

Bizzarro, J.J. 2005. Fishery biology and feeding ecology of rays in Bahía Almejas, Mexico. M.S. Thesis. Moss Landing Marine Laboratories/California State University, San Francisco. 468 pp.

———, W.D. Smith, J.F. Márquez–Farías, and R.E. Hueter. 2007. Artisanal fisheries and reproductive biology of the golden cownose ray, *Rhinoptera steindachneri* Evermann and Jenkins 1891, in the northern Mexican Pacific. Fish. Res., 84(2): 137–146.

Blake, M.C. Jr., A.S. Javko, and T.E. Moore. 1984. Tectonostratigraphic terranes of Magdalena Island, Baja California Sur. Pp. 183–191 *in* Geology of the Baja California Peninsula. (Frizzell, V.A., ed.), Soc. Econ. Paleontol. Mineral. Pac. Sec. 39.

Boggs, S.A. Jr. 2001. Principles of stratigraphy and sedimentology. Prentice Hall, Upper Saddle River, NJ. 726 pp.

Briggs, J.C. 1974. Marine Zoogeography. McGraw–Hill, New York, NY. 475 pp.

Brusca, R.C. 1980. Common intertidal invertebrates of the Gulf of California. The University of Arizona Press, Tuscon, AZ. 513 pp.

Cáceres–Martínez, C. and S. García–Bustamante. 1990. Cultivo piloto de ostion *Crassostrea gigas* (T.) en costales sobre estantes en la zona intermareal en la Bahía Magdalena, B.C.S., influencia de la densidad sobre el crecimiento. Pp. 269–278 *in* La aquacultura en México. De los conceptos a la producción. (Lanza–Espino, G. and J. Arredondo–Figuera, eds.) Instituto de Biologia, Universidad Autónoma de México, Mexico City, Mexico.

Casas–Valdez, M.M. 1987. Distribución en tiempo y espacio de las especies de sardina y macarela en Bahía Magdalena, B.C.S., México. Investig. Mar. CICIMAR, 3(2): 11–30.

———, G. Ponce–Díaz, A. Hérnandez–Llamas, M.A. González–Ojeda, F. Galván–Magaña, E. Guzmán–Vizcarra, S. Hernández–Várquez, A. Vélez–Barajas, and A. Sui–Qui. 1996. Recursos pesqueros y acuícolas de Baja California Sur: estado actual y perspectivas de aprovechamiento y desarollo. Pp. 1–14 *in* Estudio del potencial pesquero y acuícola de Baja California Sur. (Casas–Valdez, M.M. and G. Ponce–Díaz, eds.), Semarnap, Gob. del Edo. de B.C.S. FAO, UABCS, CIBNOR, CICIMAR–I.P.N., CRIP y Cet. Del Mar La Paz.

Casillas, R., R. Ruiz, F.J. Magallon, J. Arvizu, and G. Portillo. 1988. Crecimiento invernal de camaron azul (*Penaeus stylirostris*) sometido a condiciones de cultivo rustico en Puerto Chale, B.C.S., México. Rev. Latinoam. Acuicult., 36:62–71.

Castro–Aguirre, J.L. and R.T. Torres–Orozco. 1993. Consideraciones acerca del origen de la ictiofauna de Bahía Magdalena–Almejas, un sistema lagunar de la costa occidental de Baja California Sur, México. An. Esc. Nac. Cienc. Biol., Méx., 38:67–73.

Castro–Barrera, T. 1975. Ictioplankton de Bahía Magdalena, Baja California Sur. Cienc. Mar., 2(2): 10–36.

Chaves–Rosales, S. and S.C. Gardner. 1999. Recent harbour seal (*Phoca vitulina richardsi*) pup sightings in Magdalena Bay, Baja California Sur, Mexico. Aquat. Mamm., 25(3): 169–171.

Connolly, R.M. 1994. A comparison of fish assemblages from seagrass and unvegetated areas of a southern Australian estuary. Aust. J. Mar. Freshw. Res., 45(6): 1033–1044.

Cota–Meza, M.S., M.J. Haro–Garay, and R.V. Massé–Zendejas. 1992. Distribución y abundancia de quetognatos en el complejo lagunar de Bahía Magdalena Baja California Sur, México durante el ciclo estacional 1988–1989. Investig. Mar. CICIMAR, 7(2): 47–59.

Cruz–Agüero J. de la, F. Galvan–Magaña, L.A. Abitia–Cárdenas, J. Rodríguez–Romero, and F.J. Gutiérrez–Sánchez. 1994. Lista sistematica de los peces marinos de Bahía Magdalena, Baja California Sur (México). Cienc. Mar., 20(1): 17–31.

Dall, W.H. 1918. Descriptions of new species of shells, chiefly from Magdalena Bay, Lower California. Proc. Biol. Soc. Wash., 51:5–8.

Dawson, A.G. 1992. Ice age earth: late Quaternary geology and climate. Routledge, New York, NY. 293 pp.

Emilia–González, N. 1993. Moluscos endémicos del Pacífico de México. Pp. 223–252 *in* Biodiversidad marina y costera de México. (Salazar–Vallejo, S.I. and N.E. González, eds.) Com. Nal. Biodiversidad–Centro Investig, Quintana Roo, Mexico.

Environmental Systems Research Institute, Inc. 2002a. ArcView v3.3. Redlands, CA.

Environmental Systems Research Institute, Inc. 2002b. ArcGIS v8.2. Redlands, CA.

Félix–Pico, E.F. and F.A. García–Domínquez. 1993. Macrobenthos sublitoral de Bahía Magdalena, B.C.S. Pp. 389–410 *in* Biodiversidad marina y costera de México. (Salazar–Vallejo, S.I. and N.E. González, eds.) Com. Nal. Biodiversidad–Centro Investig, Quintana Roo, Mexico.

———, H.A. Salaices–Polanco, F.M. Alvarez, and A. Alvarez. 1986. Informe final: ecologia de la fauna macrobentónica litoral de las costas de Baja California Sur. CICIMAR –Inst. Nac. Pesca. La Paz, B.C.S., 43 pp.

Félix–Uraga, R., R.M. Alvarado–Castillo, and R. Carmona–Piña. 1996. The sardine fishery along the western coast of Baja California, 1981–1994. CalCOFI, 37:188–192.

Flores–Castanon, A. 1980. Prospeccion de los camarones comerciales (genero *Penaeus*) en el sistema lagunario Bahía Magdalena–Almejas, B.C.S. Mem. Simp. 2 Latino Americano Acuacultura, 1: 1303–1360.

Folk, R.L. 1974. Petrology of Sedimentary Rocks. Hemphill Publishing Co, Austin, TX. 182 pp.

Frizzell, V.A. Jr. 1984. The geology of the Baja California Peninsula. Pp. 1–7 *in* Geology of the Baja California Peninsula. (Frizzell, V.A., ed.), Soc. Econ. Paleontol. Mineral. Pac. Sec. 39.

Funes–Rodríguez, R., R. González–Armas, and R. Avendaño–Ibarra. 1998. Distribución y abundancia de las larvas de peces en el sistema lagunar de Bahía Magdalena–Almejas, Baja California Sur, México. Hidrobiológica., 8(1): 55–66.

Galván–Magaña, F., F. Gutiérrez–Sánchez, L.A. Abitia–Cárdenas, and J. Rodríguez–Romero. 2000. The distribution and affinities of the shore fishes of the Baja California Sur lagoons. Pp. 383–398 *in* Aquatic ecosystems of Mexico: status and scope. (Munawar, M., S.G. Lawrence, I.F. Munawar, and D.F. Malley, eds.) Backhuys Publishers, Leiden, The Netherlands.

Gárate–Lizárraga, I. 1992. Variación espacio–temporal de la abundancia fitoplanctónica y de la estructura de las asociaciones microfitoplanctónicas en el Sistema Laguna Magdalena–Almejas, durante 1984–1986. Masters Thesis. CICIMAR–Inst. Nac. Pesca. La Paz. B.C.S., 84 pp.

——— and D.A. Siqueiros–Beltrones. 1998. Time variation in phytoplankton assemblages in a subtropical lagoon system after the 1982–1983 "El Niño" Event (1984 to 1986). Pac. Sci., 52(1): 79–97.

——— and G. Verdugo–Díaz. 2001. Checklist of marine phytoplankton in a subtropical lagoon system in Baja California Sur, Mexico, from 1980 to 1989. Pp. 265–289 *in* Biological collections and biodiversity. (Rushton, B.S., P. Hackey, and C.R. Tyrie, eds.) Linn. Soc.–Westbury Books, London, England.

———, ———, and D.A. Siqueriros–Beltrones. 2001. Variations in phytoplankton assemblages during 1988–1989 in a subtropical lagoon system on the west coast of Mexico. Oceánides, 16(1): 1–16.

Garcia, E. 1973. Modificaciones al sistema de clasificación climática de Köppen. Universidad Nacional Autónoma de México, Mexico City, Mexico. 246 pp.

Garth, J.S. 1960. Distribution and affinities of the brachyuran Crustacea. Symposium: the biogeography of Baja California and adjacent seas. Syst. Zool., 9(3–4): 105–123.

Guardado–France, V.M. 1976. Estudios ecologicos de elasmobranquios en la zona de Bahía Magdalena, B.C.S. Bachelors Thesis. Universidad Autónoma de Baja California, Ensenada, B.C., Mexico. 135 pp.

Guerrero, R.R., D.R. Cervantes, and I.A. Jiménez. 1988. Nutrient variation during a tidal cycle at the mouth of a coastal lagoon in the Northwest of Mexico. Indian J. Mar. Sci., 3:235–237.

Gutiérrez–Sánchez, F.J. 1997. Ecologia de peces de fondos blandos del complejo lagunar Bahía Magdalena, B.C.S., México. Masters Thesis. CICIMAR, La Paz, Mexico. 84 pp.

Gutiérrez–Uribe, M.C. 1987. Composición específica de la captura de "escama" (pesqueria artisanal) en Bahía Magdalena, Baja California Sur, México. Masters Thesis. Universidad Nacional Autónoma de México, Mexico City, Mexico. 61 pp.

Hall, C. 1964. Shallow water marine climates and molluscan provinces. Ecology, 45(2): 226–234.

Hastings, P.A. 2000. Biogeography of the tropical eastern Pacific: distribution and phylogeny of chaenopsid fishes. J. Linn. Soc. Lond. Zool., 128:319–335.

Hendrickx, M.E. 1993. Crustáceos decápodos del Pacífico Mexicano. Pp. 271–318 *in* Biodiversidad marina y costera de México. (Salazar–Vallejo, S.I. and N.E. González, eds.) Com. Nal. Biodiversidad–Centro Investig, Quintana Roo, Mexico.

Hewitt, R. 1981. Eddies and speciation in the California Current. CalCOFI, 22:96–98.

Hubbs, C.L. 1948. Changes in the fish fauna of western North America correlated with changes in ocean temperature. J. Sears Found. Mar. Res., 7(3): 459–482.

Hubbs, C. 1960. The marine vertebrates of the outer coast. Symposium: the biogeography of Baja California and adjacent seas. Syst. Zool., 9(3–4): 134–147.

Ibarra–Obando, S.E., V.F. Camacho–Ibar, J.D. Carriquiry, and S.V. Smith. 2001. Upwelling and lagoonal ecosystems of the dry Pacific coast of Baja California. Pp. 315–330 *in* Ecological studies. Vol. 144: coastal and marine ecosystems of Latin America. (Seeliger, U. and B. Kjerfve, eds.) Springer–Verlag, Berlin, Germany.

INEGI. 2000. Anuario estadistco del estado de Baja California Sur. Mexico City: Instituto Nacional de Estadistica, Geografia, e Informatica.

Inman, D.L. and E.C. Nordstrom. 1971. On the tectonic and morphologic classification of coasts. J. Geology., 79:1–21.

Koch, V., J.M. Mazón–Suástegui, F. Sinsel, M. Robles–Mungaray, and D. Dunn. 2005. Lion's paw scallop (*Nodipecten subnodosus*, Sowerby 1835) aquaculture in Bahía Magdalena, Mexico: effects of population density and season on juvenile growth and mortality. Aquaculture Res., 36(5): 505–512.

Lambeck, K. and J. Chappell. 2001. Sea level through the last glacial cycle. Science, 292:679–686.

Lankford, R.R. 1977. Coastal lagoons of Mexico. Their origin and classification. Pp. 182–216 *in* Estuarine processes. Volume II: circulation, sediments, and transfer of material in the estuary. (Wiley, M.L., ed.) Academic Press, New York, NY.

Lluch–Belda, D., M.E. Hernández–Rivas, R. Saldierna–Martínez, and R. Guerrero–Caballero. 2000. Variabilidad de la temperatura superficial del mar en Bahía Magdalena, B.C.S. Oceánides, 15(1): 1–23.

Love, M.S., C.W. Mecklenburg, T.A. Mecklenburg, and L.K. Thorsteinson. 2005. Resource inventory of marine and estuarine fishes of the west coast and Alaska: a checklist of north Pacific and Artic Ocean species from Baja California to the Alaska–Yukon border. United States Geological Survey, Biological Resources Division, Seattle, WA. 276 pp.

Lynn, R.J. and J.J. Simpson. 1987. The California Current System: the seasonal variability of its physical characteristics. J. Geophys. Res., 92(C12): 12947–12966.

———, F.B. Schwing, and T.L. Hayward. 1995. The effect of the 1991–1993 ENSO on the California Current system. CalCOFI, 36:57–71.

MacMahon, J.A. 1997. Deserts. The National Audubon Society Nature Guides. Alfred A. Knopf, Inc, New York, NY. 640 pp.

Maeda–Martínez, A.N., P. Ormart, L. Mendez, B. Acosta, and M.T. Sicard. 2000. Scallop growout using a new bottom–culture system. Aquaculture, 189:73–84.

Margalef, R. 1969. Comunidades planctónicas en lagunas litorales. Pp. 545–563 *in* Memoires de un simposio internacional de lagunas y costeras. (Ayala, A. and F.B. Phleger, eds.) Universidad Nacional Autónoma de México–United Nations Educational, Scientific and Cultural Organization, Mexico City, Mexico.

Mariano–Meléndez, E. and C.J. Villavicencio–Garayzar. 1998. Cuatro tiburones y una raya en la costa noroccidental de México. Rev. Biol. Trop., 46(2): 465–467.

Mathews, C.P. 1975. El desarrollo de la zona de Bahía Magdalena. Un panorama biosocio–economico en una region en pleno desarrollo. Cienc. Mar., 2(1): 47–50.

Mathews, C. and J. Druck–Gonzalez. 1974a. Potencial pesquero y estudios ecológicos de Bahía Magdalena I. La existencias de camarón con referencia especial al camarón de roca o camarón japonés. Cienc. Mar., 2(1): 51–57.

——— and ———. 1974b. Potencial pesquero y estudios ecológicos de Bahía Magdalena III. La existencias de rayas con especial interés a las ya aprovechadas. Cienc. Mar., 2(1): 67–72.

——— and J. Espinoza. 1974. Potencial pesquero y estudios ecológicos de Bahía Magdalena IV. La distribución y abundancia de las existencias de pescado de escama. Cienc. Mar., 2(1): 73–76.

——— and V. Guardado–France. 1974. Potencial pesqueros y estudios ecológicos de Bahía Magdalena II. Las existencias de gatas. Heterodontidae. Cienc. Mar., 2(1): 60–66.

McLain, D.R. and D.H. Thomas. 1983. Year–to–year fluctuations of the California Countercurrent and effects on marine organisms. CalCOFI, 24:165–181.

McLean, J.H. 1969. Marine shells of southern California. Los Angeles Co. Mus. Nat. Hist. Sci. Ser. 24. Zool. 11. 104 pp.

McRoy, C.P. and C. Helfferich. 1977. Seagrass ecosystems. Marcel Dekker. Inc., New York, NY. 314 pp.

Morales–Bojórquez, E. 2002. Teorema de Bayes aplicado a la estimación del rendimiento de la sardina Monterrey (*Sardinops sagax caeruleus* Girard) de Bahía Magdalena, Baja California Sur, México. Cienc. Mar., 28(2): 167–179.

Morrissey, J.F. and S.H. Gruber. 1993. Habitat selection by juvenile lemon sharks, *Negaprion brevirostris.* Environ. Biol. Fishes., 38:311–319.

National Climatic Data Center. 1994. Comprehensive Ocean–Atmosphere Data Set. National Oceanic and Atmospheric Administration. www.ncdc.noaa.gov/oa/climate/coads/.

National Imagery and Mapping Agency (NIMA). 1998. Chart #21121. Bahía Magdalena including Bahía Santa María, Bahía Almejas, and Bahía Santa Marina, Reston, VA.

Nienhuis, H. and R. Guerrero–Caballero. 1985. A quantitative analysis of the annual phytoplankton cycle of the Magdalena lagoon complex (Mexico). J. Plankton Res., 7(4): 427–444.

——— and ———. 1986. Biomasa y distribución del fitoplancton entre 1980 y 1984 en Bahía Magdalena, Baja California Sur, Mexico. CICIMAR–Inst. Nac. Pesca. La Paz. Mexico. Atlas No. 5.

Obeso–Nieblas, M., J.H. Gaviño–Rodriguez, and Á.R. Jiménez–Illescas. 1999. Modelación de la marea en el sistema lagunar Bahía Magdalena–Almejas, B.C.S., México. Oceánides, 14(2): 79–88.

Palomares–García, R. 1992. Analisis de la taxocenosis de los copepodos en el complejo lagunar de Bahía Magdalena–Almejas, B.C.S., durante 1985–1986. Cienc. Mar., 18(3): 71–92.

——— and J. Gómez–Gutiérrez. 1996. Copepod community structure at Bahía Magdalena, Mexico during El Niño 1983–1984. Estuar. Coast. Shelf Sci., 43:583–595.

———, A. Martínez–López, R. De Silva–Dávila, R. Funes–Rodríguez, M.A. Carballido–Carranza, R. Avendaño–Ibarra, A. Hinojosa–Medina, and G.A. López–Ibarra. 2003. Biological effects of El Niño 1997–98 on a shallow subtropical ecosystem: Bahía Magdalena, Mexico. Geofisica International, 42(3): 455–466.

Phleger, F.B. and G.C. Ewing. 1962. Sedimentology and oceanography of coastal lagoons in Baja California, Mexico. Geo. Soc. Am. Bull., 73:145–182.

Postma, H. 1965. Water circulation and suspended matter in Baja California lagoons. Neth. J. Sea Res., 2: 566–604.

Ramírez–Espinosa, J.A. 1990. Distribución y abundancia poblacional del lobo marino (*Zalophus californianus* Lesson, 1828) en la Isla Margarita, B.C.S., México durante la temporada otoñal. Pp. 7–24 *in* Estudio sobre el lobo marino en el noroeste de México. Sec. de Pesca, Mexico.

Ramírez–Rodríguez, E.M. 1987. Analisis preliminary de las pesquerias artesanales del area de Bahía Magdalena, B.C.S. durante 1982 y 1983. Mem. 5 Simp. Biol. Mar. Univ. Autón. B.C.S., 149–154.

Rice, D.W., A.A. Wolman, and D.E. Withrow. 1981. Gray whales on the winter grounds in Baja California. Rep. Int. Whal. Comm., 31:477–489.

Riosmena–Rodríguez, R. and J.L. Sánchez–Lizaso. 1996. El limite sur de distribución de *Zostera marina* L. y Phyllospadix torreyi Watson para el noroeste Méxicano. Oceanides, 11(1): 45–48.

Robertson, A.I. and N.C. Duke. 1987. Mangroves as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia. Mar. Biol., 96:193–205.

Robinson, C.J. and S. Gomez–Aguirre. 2004. Tidal stream use by the red crab *Pleuroncodes planipes* in Bahía Magdalena, Mexico. J. Exp. Mar. Biol. Ecol., 308:237–252.

———, J. Gómez–Gutiérrez, R. Félix–Uraga, and V. Arenas–Fuentes. 2000. Seasonal hydro–acoustical observations of small pelagic fish behaviour in Bahía Magdalena, Mexico. Aquat. Living Resour., 13(1): 11–18.

Salazar–Hermoso, F. and C. Villavicencio–Garayzar. 1999. Abundancia relative de la guitarra *Rhinobatos productus* (Ayres, 1856) (Pisces: Rhinobatidae) en Bahía Almejas, Baja California Sur, de 1991 a 1995. Cienc. Mar., 25(3): 401–422.

Salinas–Zavala, C.A., A.L. Leyva–Contreras, D. Lluch–Belda, and E. Diaz–Rivera. 1990. Distribución geográfica y variabilidad climática de los regimens pluviométricos en Baja California Sur, México. Atmósfera, 3:217–237.

Sánchez–Ortiz, C.A. and J. Gómez–Gutiérrez. 1992. Distribucion y abundancia de los estadios planctonicos de la jaiba *Callinectes bellicosus* (Decapoda: Portunidae), en el complejo lagunar Bahía Magdalena, B.C.S., México. Rev. Investig. Cient., 3(1): 47–60.

Sánchez–Rodríguez, I., M.C. Farjardo–Leon, and C. Oliveiro–Pantoja. 1989. Estudio floristico estacional de las algas en Bahía Magdalena, Baja California Sur, México. Investig. Mar. CICIMAR, 4(1): 35–48.

Santamaría–Gallegos, N.A., J.L. Sánchez–Lizaso, and R. Riosmena–Rodríguez. 2003. Life strategies of subtropical eelgrass *Zostera marina* L. populations in southern Baja California: its southern limit distribution along East Pacific. Gulf Mex. Sci., 21(1): 130–131.

Sedlock, R.L. 2003. Geology and tectonics of the Baja California peninsula and adjacent areas. Geo. Soc. Am. Spec. Pap., 374:1–41.

Shumilin, E., G.D. Rodríguez–Meza, D. Sapozhnikov, S. Lutsarev, and J. Murillo de Nava. 2005. Arsenic concentrations in the surface sediments of the Magdalena–Almejas Lagoon Complex, Baja California Peninsula, Mexico. Bull. Environ. Contam. Toxicol., 74:493–500.

Soule, J. 1960. The distribution and affinities of the littoral marine bryozoa (Ectoprocta). Symposium: the biogeography of Baja California and adjacent seas. Syst. Zool., 9(3–4): 100–104.

Spencer, J.E. and W.R. Normark. 1979. Tosco–Abreojos fault zone: a Neogene transform plate boundary within the Pacific margin of southern Baja California, Mexico. Geology, 7:554–557.

——— and ———. 1989. Neogene plate tectonic evolution of the Baja California Sur continental margin and the southern Gulf of California, Mexico. Pp. 489–497 *in* Geology of North America. The eastern Pacific Ocean and Hawaii. Winterer, E.L., D.M. Jussong, and R.W. Decker (EDITORS). 1989 Geol. Soc. Am., Boulder, Colorado.

Takasaki, T. 1913. Los recursos pesqueros de Bahía Magdalena, B.C.S. Traducción por H. Chapa–Saldaña (1962) y republicado en: S.I.C. Dir. Gen. Pesca and Ind. Com., Dep. Est. Biol. Pesq. Trab: Div. #23, 3:1–27.

Torres–Orozco, R.E. and J.L. Castro–Aguirre. 1992. Registros de peces tropicales en el complejo lagunar de Bahía Magdalena–Almejas, Baja California Sur, México. Anales Inst. Biol. Univ. Autón. México, Ser. Zool., 63(2): 281–286.

Valentine, J. 1966. Numerical analysis of marine molluscan ranges on the extratropical northeastern Pacific shelf. Limnol. Oceanogr., 11:198–211.

Villavicencio–Garayzar, C.J. 1995. Distribución temporal y condición reproductiva de las rayas (Pisces: Batoidea) capturadas comercialmente en Bahía Almejas, Baja California Sur (México). Rev. Investig. Cient. Univ. Autónoma de Baja California Sur, 6(12): 1–12.

Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. J. Geol., 30:377–392.

Young, E. 2001. State intervention and abuse of the commons: fisheries development in Baja California Sur. Ann. Assoc. Am. Geographers., 91(2): 283–306.

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